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DETERMINATION OF SURFACE ROUGHNESS OF THE LAND TEXTURE USING REMOTE SENSING DATA AND GEO-INFORMATIC TECHNIQUES: A CASE STUDY IN KURDISTAN REGION-IRAQ

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ABSTRACT

Surface roughness (SR) is a significant geomorphic factor that has been effectively applied to determine material characteristics, present and past processes, and the period passed by since development in the environmental and earth sciences. Thus, this type of study is essential for analyzing SR and its importance. The research efforts to display a coherent evaluation of techniques and remote sensing data. The digital elevation models (DEMs) data were taken into account for quantifying the SR of landscape in different scales in selected areas that belong to the Kurdistan region, north of Iraq. The various types of DEMs {ALOS PALSAR (12.5 m) and SRTM in (30 m) and (90 m) resolution} as remotely sensed data integrated with GIS techniques were used to calculate SR regarding different neighborhood sizes {51 × 51 and 100 × 100 cells moving window size (MWZ)} in the both selected areas. The first study area is a mountainous terrain characterized by a number of anticlines and synclines that are located in High Folded Zones (HFZ), while the second study area is virtually a plain that is located in Low Folded Zones (LFZ). It found that SR calculation in wide and mountainous areas can be efficiently analyzed in more detail by using coarse-resolution DEMs from large MWZ, such as 100 × 100 cells, whereas high-resolution DEMs can be considered for studying SR in small, urban, and plain areas to reach detail information regarding smaller MWZ.

The results show that the E and W segments of Safeen and the western segment of Shakrok anticlines have the highest SR values, which indicate high incision at elevated and extremely eroded parts of area one, although Bani Bawi, Pirmam, and Khatibian anticlines have moderate to low SR values due poorly incised. On the other hand, the areas within LFZ are mainly flat and have the lowest values of SR, which indicate a very poorly dissected landscape except for the northwest part of the area two relatively has a higher SR value.

INTRODUCTION

Roughness is a substantial parameter of the land surface that is utilized through the Earth and environmental sciences to help define and assess the mechanisms operating on individual landscapes (Hobson, 2019; Grohmann *et al*., 2010). Moreover, the surface roughness of the earth is a key factor for analyzing terrain as it represents multiple geophysical criteria for example characteristics of landforms in addition to playing a significant role in studying

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various natural phenomena (Hani *et al*., 2011). Surface roughness (SR) has been defined as an indicator of the heterogeneity of topographic surface altitudes at a given scale, where the analysis scale is measured by the size of the interesting landforms or geomorphic features (Grohmann *et al*., 2009). For instance, various aspects, such as landslides of various eras, as well as compassable hydrological models for flow systems have been delineated by studying relationships between the SR and geological age (Grohmann *et al*., 2010). Thus, the SR of a landform depends on the characteristics of the material, the processes that operate on it, and the duration that has passed since its formation. SR is a morphometric parameter used for understanding how the heterogeneous land surface developed. It is possible to measure SR using remote sensing by reflecting electromagnetic radiation from objects on the surface, ranging from reflectance to diffuse (Grohmann *et al*., 2010). Numerical simulation of natural landforms is helpful for geologists to understand the development of the landforms through various processes and analyze results (Luo *et al*., 1997). This method of advanced modeling could offer perceptions into the role of deposition, erosion, climate change, and tectonic effects in these surface modifications. The techniques most widely applied are based on empirical dispersion of slopes, heights, and regular vectors to slope for investigation of the SR (Shepard *et al*., 2001; Berti *et al*., 2013). The digital elevation model (DEM) has been used for the quantification of SR heterogeneity. Moreover, DEM is a significant and reliable surface elevation model that makes it suitable for the depiction of surface characteristics that specify the quantity of SR of a given engineering or environmental phenomenon (Asal, 2019). SR is considered herein not as a parameter but as a geomorphometric variable, while the latter has also been used commonly in previous studies (Minár and Evans, 2008; Grohmann *et al*., 2009). Fractal geometry analysis has been used to analyze the relationship between DEM, SR, and geological characteristics, and it has been proposed that DEM-based SR measurement is a valuable method to identify morphometric characteristics (Asal, 2019). The local variation of surface gradients or curvatures is characterized by the digital terrain model (DTM) derived roughness and allows distinction between rough and smooth landforms or components of landforms (Korzeniowska and Korup, 2016). Hence, the terrain is an important component for spatial process modeling, such as hydrological, geological, and natural disaster processes the content of terrain analysis can be extended to several terrain information processes regarding other geo-information data (Hu *et al*., 2015). In order to generate a map of erosion variances and increased topographical surfaces, a combination of the SR and the hypsometric integral has been proposed, which could be conveniently compared with the known structural framework (Andreani *et al*., 2014). The SR characteristics as generally attained from the analysis of elevation differences found across samples, from which the elevation of the root mean square (RMS), the length of correlation, and the function of autocorrelation are typically determined as the input(s) to multispectral models (Gharechelou *et al*., 2018). Riley *et al*. (1999) proposed a basic methodology which measures SR by determining the elevation or slope variability in a particular neighborhood. Zebari *et al*. (2019) employed SR as one of the most crucial geomorphic indices regarding the Shuttle Radar Topography Mission (SRTM) and TanDEM-X to estimate tectonic activity and landform evolution in the Iraqi Kurdistan Region. Moreover, the SR has been used to assess the relative evolution of anticlines scenery northwest part of the Zagros Mountain Front Flexure in the Iraqi Kurdistan Region (Zebari *et al*., 2018). Similarly, Sajadi *et al*. (2021) used morphotectonic indexes (including RS) to assess the impacts of tectonic activities on the evolution of watersheds and drainage patterns in the Iranian Kurdistan Region with regard to ASTER DEM v3 data. Al-Attar *et al*. (2022) used SRTM data to assess the comparative level of tectonic activity in the Great Zab Watershed concerning quantitative and statistical techniques.

Frankel and Dolan (2007) proposed a technique dependent on slope variations and differences, via assessing the standard deviation (SD) of the local slope of each cell and its neighbors regarding 5 x 5 cells moving window size (MWZ). Several recent techniques of analysis SR at various scales and resolutions have been compared and reviewed by (Grohmann *et al*., 2010). They used a ratio technique that calculates the ratio between real surface area and flat area of pixels or cells, the results showed that this ratio would be equal to one on flat surfaces, but for uneven surfaces, the ratio would be greater than one. It was indicated that neighborhood size is effective for evaluating SR statistics regarding the resolution of selected data. SR is described as the heterogeneity of the surface elevations of the earth to be interpreted as the absolute SD of all values inside the MWZ identified by the user (Asal, 2019; Grohmann *et al*., 2009). DEM is expressed in the ability to derive geomorphometric features, such as SR that provide regional geomorphology details and specific roughness criteria (Asal, 2019). SR indices have been proposed for assessing SR view for applications of InSAR data of various land cover groups and DEMs of various elevations dependent on the heights variations among neighboring cells or pixels inside a selected MWZ by the user (Tay and Teng, 2008). SR has been estimated from LiDAR DEMs as overall curvature SD in a defined MWZ (5 × 5 pixels) and used for interpretation of the SR analysis (Korzeniowska and Korup, 2016). Recently, the most commonly used data for extracting various surface parameters like SR are DEMs data, particularly, those derived from active or microwave remote sensing like airborne laser scanning, LiDAR, and Radar ranging (Asal, 2019). The Sentinel-1 data were used for assessing the SR, but the findings revealed that roughness parameterization was overestimated (Gharechelou *et al*., 2018).

SR is one of the most important factors or indicators used to obtain information about happing various natural geo-environmental disasters, forms of terrain, and developments. Therefore, evaluating the different methods and data used for the determination of SR would be valuable for further understanding. The research attempts to appraise and examine the determination of SR of landforms by using remotely sensed data in terms of DEMs in selected areas (Iraqi Kurdistan Region). Furthermore, the key objective is to compare the data and methods used to calculate SR in terms of DEM resolution and MWZ and to propose the most relevant one as a framework for future research.

DESCRIPTION OF STUDY AREA

Geographically, the study area is situated northeast and southwest of Erbil city, Kurdistan Region, northern Iraq (Figure 1). The selected areas cover around 1745 Km^2 and 1159 Km^2 for areas 1 and 2, respectively, area one contains the main structural folds including Safeen, Shakrok, Bani Bawi, Pirmam, and Khatibian anticlines, which are located within the High Folded Zone (HFZ), the area two is the relatively flat area covered mainly by small hills and recent deposits belong to the Low Folded Zone (LFZ). The elevation distribution of area one ranges from 340 to 1970 m above sea level, which comprises steep and gentle slopes, while the elevation of area two ranges from 270 to 515 m above sea level, which is generally a plain area. The Kurdistan Region is located in the northeast part of the Arabian Plate. The site is structurally placed within the Zagros Fold-Thrust Belt's northwest segment (Zebari and Burberry, 2015). Zagros convergence affected and controls all structural developments and landform deformations in the area (Jassim and Goff, 2006). The geology of the study areas is described by various types of sedimentary rocks, the age of exposed formations ranging from Late Cretaceous to recent sediment (Quaternary period). Many formations are distributed within the study area, they are represented by: Qamchuqa, Bekhme, Shiranish, Kolosh, Sinjar, Khurmala, Gercus, Avanah, Pila Spi, Fatha, and Injana formations and recent Quaternary sediments (Sissakian and Fouad, 2014; Omar, 2011; and Fatah *et al*., 2020). The geomorphological description of the selected area obviously depends on the geological formations' structural framework and lithological properties and other parameters like climate and rate of degradation. In the studied area, several drainage patterns are also due to structural origins (fracture sets) and variability in rock competence (Dosky, 2002).

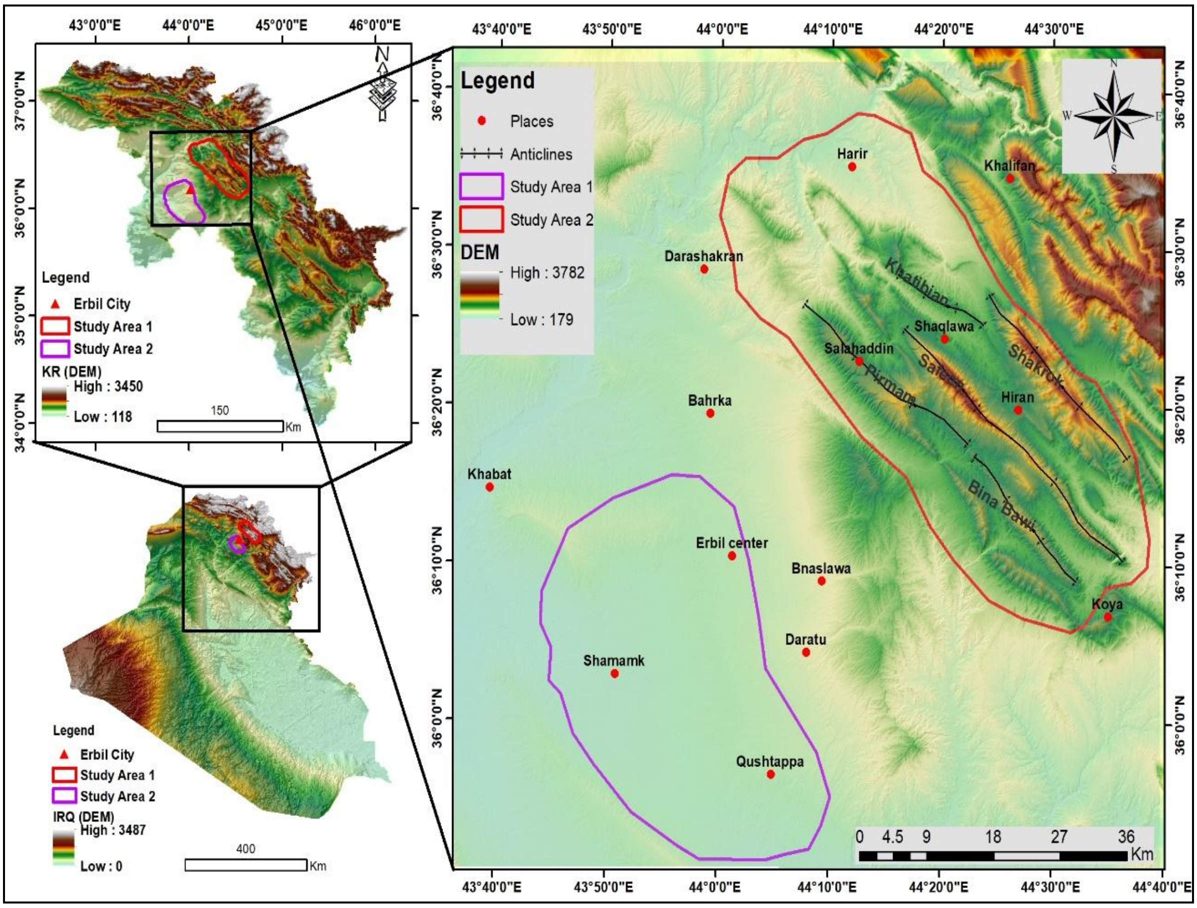

Figure 1: The location map shows the elevation distribution in the selected areas in meters.

MATERIALS AND METHODOLOGY

In recent decades, a number of researchers have significantly considered SR analysis to assess different earth and environmental activities. Several methods and data have been utilized to estimate SR. This part has described the various definitions, approaches, and implementations of SR. This is expected not to include a detailed review of the topic, but to introduce the readers and authors with effective approaches and data found in the literature.

The SR measures or procedures how much a region differs from being completely plane. It is conducted that SR values near 1 indicate flat or smooth surfaces while irregular or uneven surfaces are shown by higher values of SR. It rises with the growth in cut-by streams. This equation was used for calculating the SR (Hobson, 2019; Grohmann and Geosciences, 2004).

$$\text{Surface roughness (SR)} = \frac{\text{Topographic surface area (m}^2\text{) }(TS)}{\text{Flat surface area (m}^2\text{) }(FS)} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

The introduction of higher computational capacities, the advent of recent developments in technology like GIS, remote sensing, and the accessibility of spatial 3-dimensional datasets have contributed to a simple calculation of the roughness values. Therefore, since altitude data for many metropolitan areas is not readily available, many researchers have used remotely sensed data to measure the roughness values for those areas (Yuan *et al*., 2014). Abbas *et al*. (2020) used the satellite data approaches, which are assisted by GIS and remote sensing as potential and effective techniques for mapping SR in Iraq concerning the NDVI tool, and it was a scientific approach applied in his study considered the first experimental tool for achieving SR for large areas, such as Iraq. Frankel and Dolan (2007) have fruitfully used digital topographic data such as high-resolution (ALSM) airborne laser swath mapping for quantifying and evaluating SR of alluvial fans in arid regions with regarding 5 × 5 m MWZ for SD of slope technique. Its wide availability of all regional high-resolution data sets (e.g., NextMap Britain) and national moderate data sets, such as SRTM or the Global ASTER DEM, make them perfectly adapted to this sort of research, while caution should be taken regarding the suitability of source data (Grohmann *et al*., 2010). It is mentioned that the availability, extent, and resolution of DEM have been enhanced by current improvements in technology. These kinds of datasets have been widely used for determining the SR that applies in various aspects of earth science to understand the landscape developing processes (Smith, 2014).

The advanced method has been used for evaluating SR factors, 3D laser scanner or interferometry was applied to assess urban area SR in commercial software (Tonietto *et al*., 2019). Smith (2014) discussed using LiDAR data to estimate topography roughness, which is useful for identifying landslides automatically, distinguishing the failure areas, and offering symptomatic dating of units of landslide. Similarly, SR based on LiDAR has been utilized to evaluate comparative ages of alluvial fans, and SR morphometric descriptions are frequent in earth science aspects (Frankel and Dolan, 2007). Grater SR of soils sustains greater rates of infiltration, and about 20 – 200 % of infiltration rates could be increased by SR (Smith, 2014). Jhaldiyal *et al*. (2016) conducted those elements of SR that could be effortlessly and effectively analyzed by morphometric-based approaches, which are the integration of remote sensing and GIS methods regarding DEM and photogrammetry.

Choosing MWZ plays a key role in computing the quantity of SR based on the research's purposes. Thus, the selection of MWZ from one study to another is different. The neighborhood size alteration was used for a multi-scale study (Grohmann *et al*., 2009). It is suggested that freely accessible SRTM DEM data including 30m and 90m spatial resolution have been commonly utilized for observing landforms development and SR analysis. The 15 × 15 cells were used as a size window for calculating the geomorphic indices to evaluate the landscape information (Andreani and Gloaguen, 2016). Moreover, Grohmann *et al*. (2010) have used different MWZ for evaluating the scale effects of SR such as from 3 × 3 pixels to 51 × 51 pixels regarding various DEMs, also the impacts of spatial resolution of DEM were evaluated to detect the best one for studying surface irregularity. Berti *et al*. (2013) suggested that a 3 × 3 window size was suitable for SR analysis in detail for small areas. On the other hand, Zebari *et al*. (2019) used 100 × 100 cells MWZ for computing the geomorphic indexes including SR to assess the relative time of uplifting and landforms evolution beside the Zagros Fold-Thrust belt in the Kurdistan Region, north of Iraq. They mentioned that the selection DEM based-MWZ has a potential impact on the calculation and results of geomorphic indexes. Furthermore, Amine *et al*. (2020) used the SR index combine with other geomorphic indices applied to DEM data to analyze the degree of landscape maturity in terms of erosion and uplifted surface in the northwestern part of Morocco. The 100 × 100 cells

MWZs were proposed for their study because this window size is more suitable for studying large area for example broad anticlines more than 3 Km.

The suitable data and methods have been selected and applied for this investigation based on the suggestions of previous studies. For this research, we processed and applied DEMs from a variety of sources to examine and visualize how spatial resolution affects SR calculation. These DEMs include the Advanced Land Observing Satellite (ALOS PALSAR) DEM with a resolution of 12.5 m and SRTM in 1-arc-sec (~30 m) and 3-arc-sec (~90 m) resolutions. First, DEMs were used to calculate the slope in degrees, and then SR was calculated for various abovementioned DEMs data. The SR is computed by dividing the real topographic surface area by the flat surface area using equation (1), which was initially developed by Hobson (2019), and subsequently, it has even become a more reliable and valuable method that is frequently used by many authors in their studies (Amine *et al*., 2020; Zebari *et al*., 2019). Additionally, moving window sizes of 51 × 51 cells and 100 × 100 cells were evaluated and used to calculate SR in order to make the results more understandable and reasonable. According to previous studies, the selected window sizes are more appropriate, acceptable, and reliable for SR analysis in large-scale and mountainous regions such as wide anticlines and broad areas (Zebari *et al*., 2019; Grohmann *et al*., 2010). The two areas have been selected in order to compare the SR in mountainous and plain areas and to select suitable MWZ and DEM data in various types of terrain. ArcGIS 10.4 software has been used effectively to calculate the SR regarding the spatial analyst tools.

RESULT AND DISCUSSION

Integration of remote sensing and GIS methods has been widely applied for various studies, and several researchers recently using these techniques for determining the SR for various purposed applications. Remotely sensed data and GIS approaches, along with the accessibility of adequate LC/LU data are very useful in observing and estimating the SR of any region in a process that significant cost, time, and effort efficiency techniques (Abbas *et al*., 2020). For instance, Andreani and Gloaguen (2016) indicated the Tuxtla fault scarp as modern and dominant morphology by low values of SR.

It has been discussed that slope is one of the most important factors for evaluating and controlling the dynamic process on the earth and morphometric of the earth, and the slope is the main factor that is used for determining SR (Smith, 2014; and Andreani and Gloaguen, 2016). The slope distribution over the selected areas for this study has been shown in Figure 2. It seems that the slope in mountainous areas is higher compared to the plain areas, and generally, the area covered by anticlines has the maximum slope value such as in Safeen and Shakrok anticlines. However, Harir Plain has the lowest slope values in area one, while area two generally flat surfaces its slope under 8 degrees except for the northwest parts of area two. However, this is a different slope degree for selected various DEMs data, but generally slope ranges from 0 to 76 degrees in area one, whereas slope of the area two ranges from 0 to 29 degrees. It is generally accepted that a higher slope degree indicates increasing SR in the area (Andreani and Gloaguen, 2016). Therefore, it is estimated that the mountainous regions have higher SR due to the degree of erosion and tectonic impacts on the areas, while area two as a flat area has low slope values (Zebari *et al*., 2019).

Moreover, elevation and hillshade maps have been produced for the area to observe topographic variation and irregularity of the surface in the visual aspect (Figures 3 and 4). It was indicated that elevation and hillshade are two other parameters that were used for analyzing topographic variations and play a key role to assess SR (Berti *et al*., 2013). When the variation in topography increases also the degree of irregularity of the surface will be increased. The elevation variation of area one is between 341 m to 1972 m above sea level, and differences are noticeable because of a number of anticlines and synclines located within area one, which belongs to HFZ. While the topographic variation is low in area two, which is located in the LFZ, it ranges from 271 m to 514 m regarding combination value from all selected resolutions, and this area is almost plain excluding the northwestern part. The hillshade is used to visualize the topography of the areas in almost 3D representation. The SR has been calculated to detect morphological landforms in the selected area and compare mountains and plains areas.

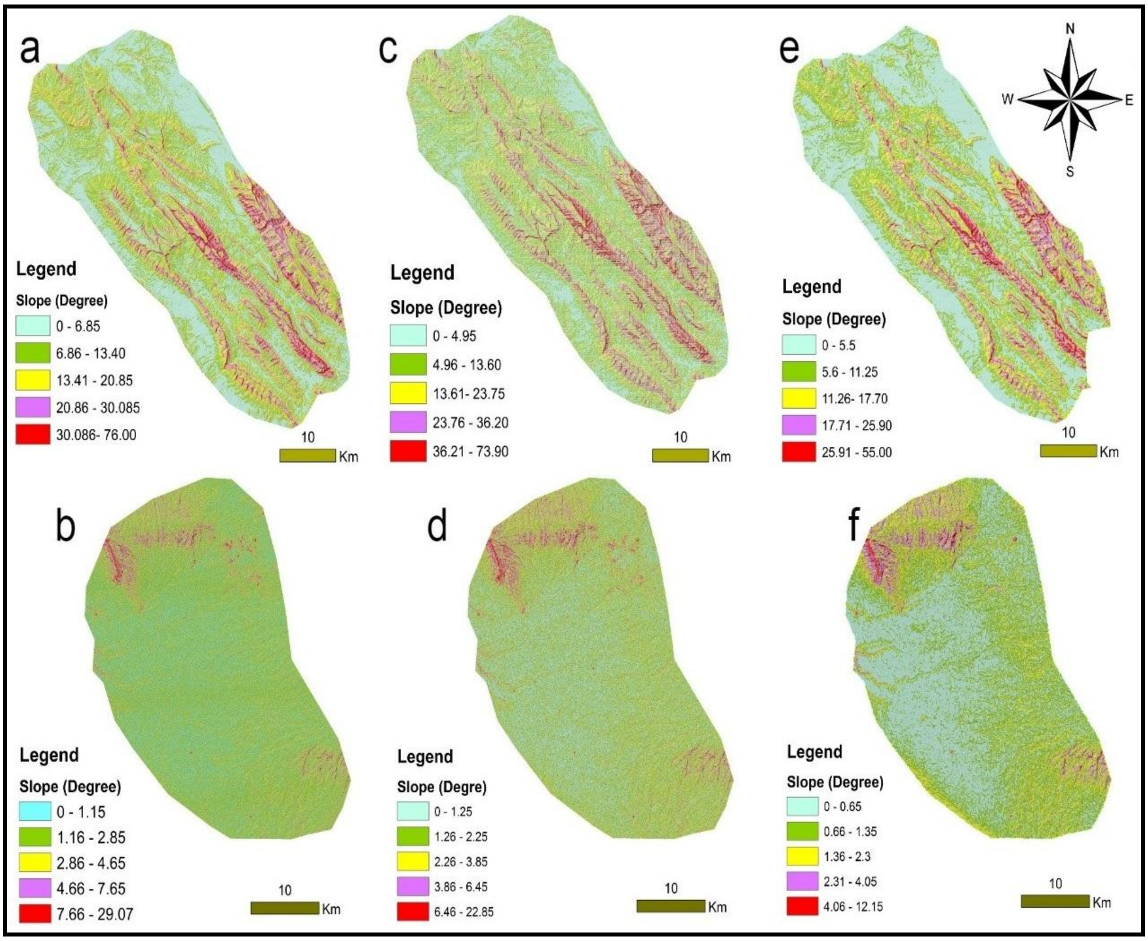

Figure 2: Slope maps in the investigated area **(a and b)** extracted from ALOS PALSAR DEM (12.5 m), **(c and d)** extracted from SRTM DEM (30 m), and **(e and f)** extracted from SRTM DEM (90 m).

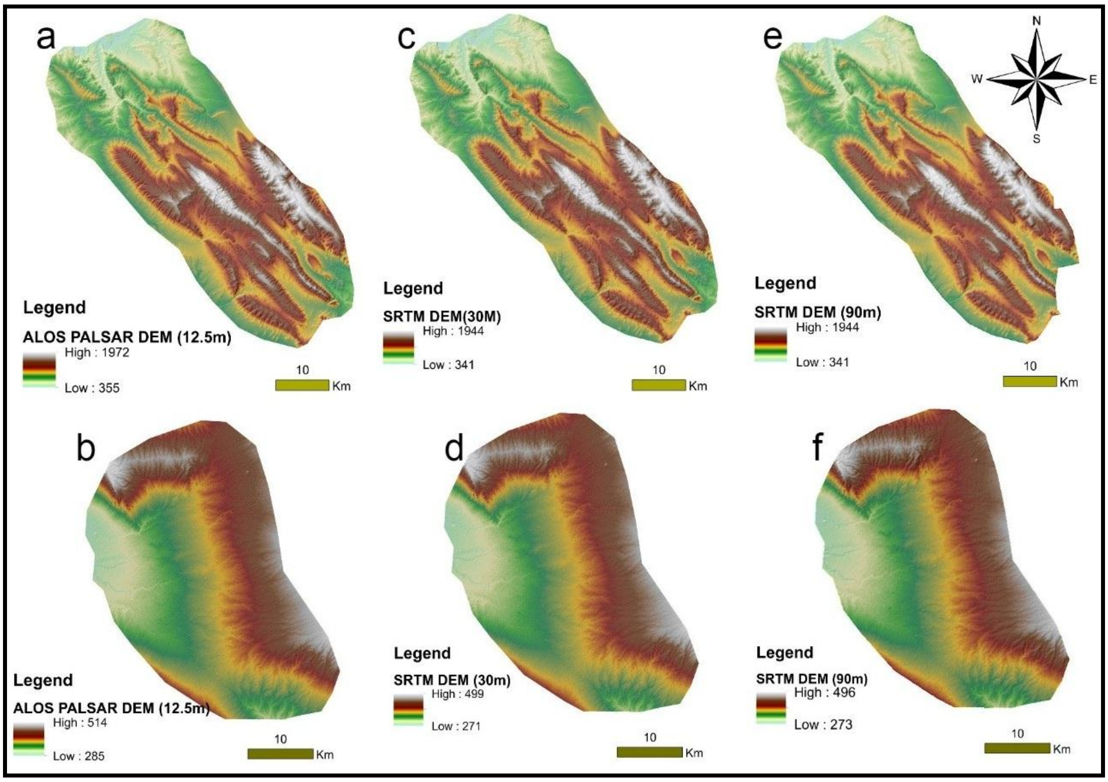

Figure 3: Elevation maps (in terms of DEMs) of the investigated areas; **a and b)** ALOS PALSAR DEM (12.5 m), **c and d)** SRTM DEM (30 m), and **(e and f)** SRTM DEM (90 m).

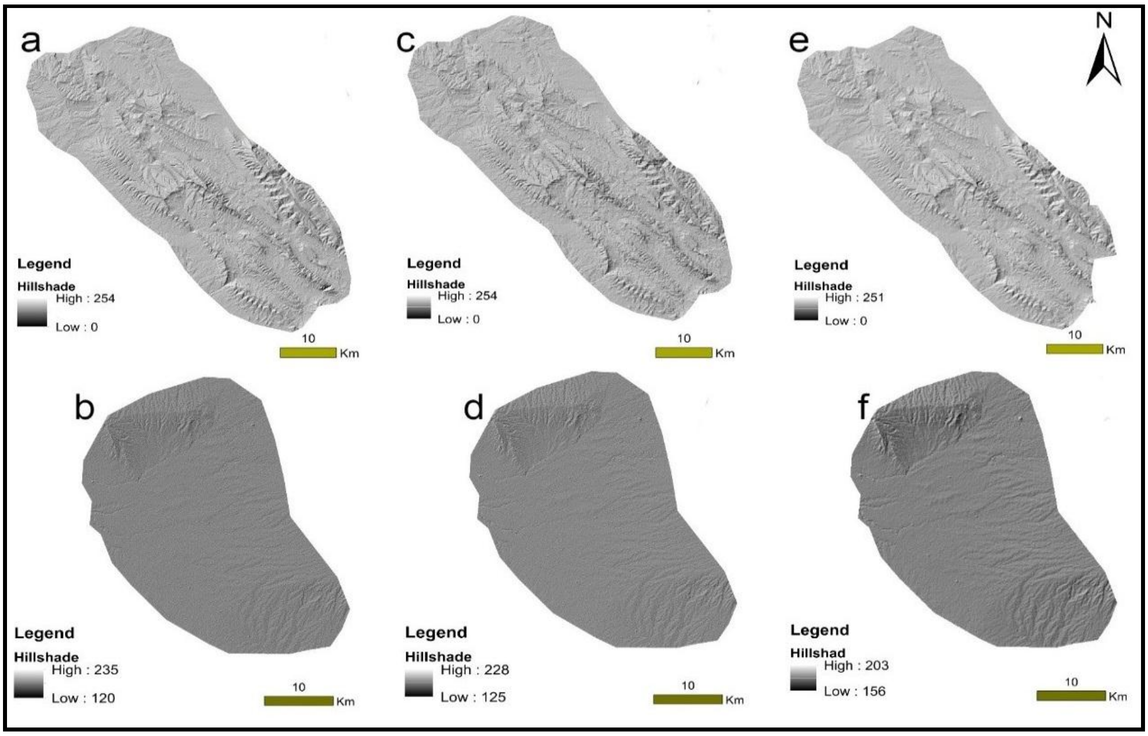

Figure 4: Hillshade maps in the investigated areas; **a and b)** of ALOS PALSAR DEM (12.5 m), **c and d)** of SRTM DEM (30 m), and **(e and f)** of SRTM DEM (90 m).

Berti *et al*. (2013) discussed that the influence of DEM resolution variation was not explored since low-resolution DEMs were inappropriate for mapping dynamic earthflows. However, in the examined sites, the topographic characteristic of earthflows is really different and they could also be identified utilizing coarse-resolution DEMs. The accuracy of the estimation declines with DEM resolution to the coarse one, but perhaps the results are still reasonable and acceptable. Therefore, the SR values have been derived from different types of DEM resolutions including ALOS PALSAR DEM (12.5 m), SRTM DEM (30 m), and SRTM DEM (90 m) for both selected areas in this study (Figure 5). The three different types of DEMs were adopted in this research in order to assess them with different MWZs for various terrain areas in terms of SR. Moreover, the adopting various type of DEMs to suggest a more reasonable and suitable research framework for future studies to compute SR accurately. Figure 5 demonstrates the SR of the selected areas. The SR values of the area one range from 1 to 4.1214, 1 to 3.5987, and 1 to 1.7434 for ALOS PALSAR DEM (12.5 m), SRTM DEM (30 m), and SRTM DEM (90 m), respectively (Figures 5a, c and e), while the values of SR in area two are ranged from 1 to 1.1440, 1 to 1.0848, and 1 to 1.0228 for the same above order of DEMs resolutions, respectively (Figures 5b, d and f). It is indicated that higher resolution DEM such as ALOS PALSAR DEM (12.5 m) has higher variation in values of SR compared to others and the range of SR values decreases with decreasing the resolution of DEM. The flat areas, in the surrounding synclines and the plunging tips of the anticlines, are represented by the lowest values of the SR, while the hinge of anticlines and water gaps areas are indicated via the highest values of SR due to extremely incised and presence of wind gaps which indicated the advanced stage corrosion and more maturity landforms.

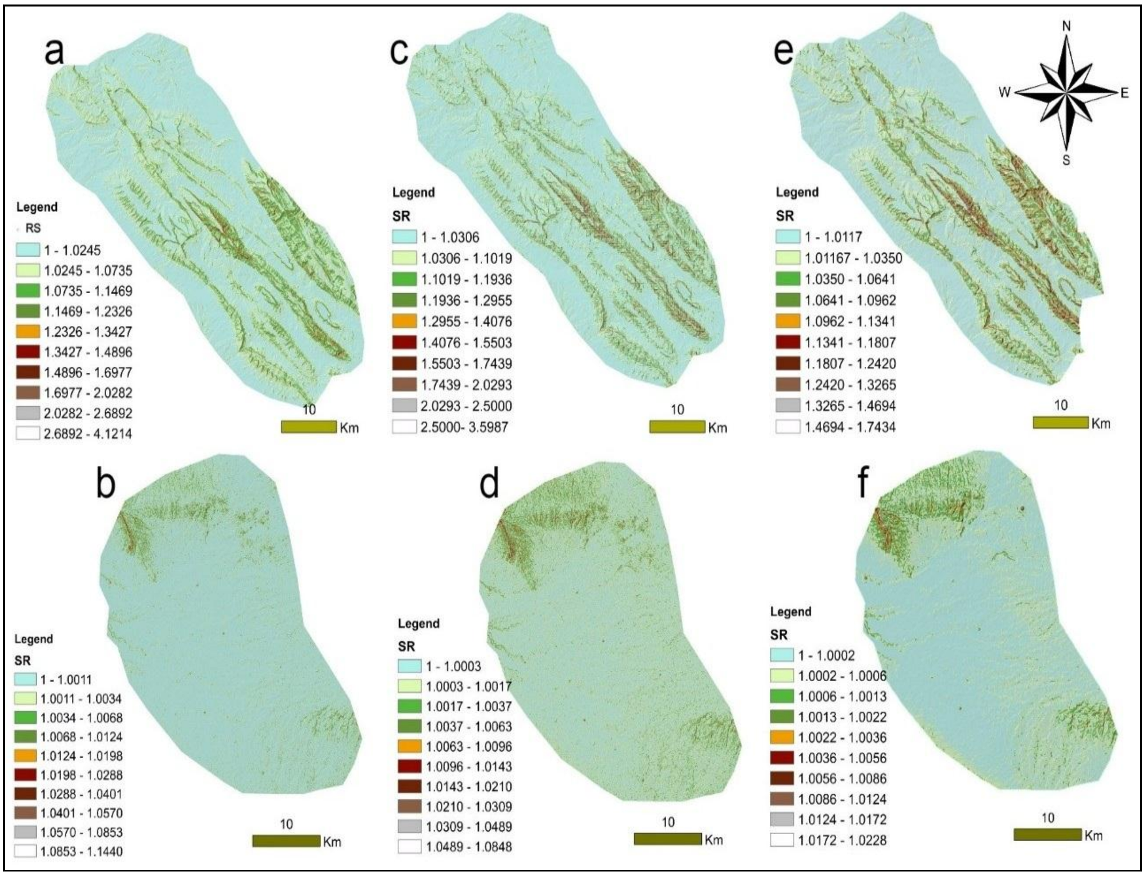

Figure 5: Surface roughness (SR) maps in the investigated areas; **a and b)** of ALOS PALSAR DEM (12.5 m), **c and d)** of SRTMDEM (30 m), and **(e and f)** of SRTM DEM (90 m).

On the other hand, the moving window size (neighborhood size) technique was commonly used for observing and analyzing SR particularly, and selecting window sizes is distinctly based on objectives, area scale, and detail studies because MWZ has potential influences on the results of SR (Berti *et al*., 2013; Andreani and Gloaguen, 2016). (51 × 51 and 100 × 100 cells) MWZs have been selected and used for calculating SR values in selected areas. The MWZ must be greater than the standard wavelength of the interested and observed features for the study (Shepard *et al*., 2001). It is indicated that the elements of large landscapes could not represent properly by small MWZ, whereas small features are demolished across broad regions (Grohmann *et al*., 2010). Hence, appropriate choices for studying large-scale SR were used, such as the selected areas for this study which contain wide plain, anticlines, and synclines that require large MWZ as Zebari *et al*. (2019) also used the 100 × 100 pixels neighborhood size for studying SR.

Figure 6 shows that the outcomes of SR calculations were computed from 51 × 51 pixels MWZ on all three types of selected DEMs resolutions for both studied areas. The values of SR in area one varied from 1 to 1.3564, 1 to 1.7130, and 1 to 1.1134 for ALOS PALSAR DEM (12.5 m), SRTM DEM (30 m), and SRTM DEM (90 m), respectively (Figures 6a, c and e), although SR values of area two are ranged from 1 to1.0332, 1 to 1.0260, and 1 to 1.0070 for the same above order of DEMs resolutions, respectively (Figures 6b, d and f).

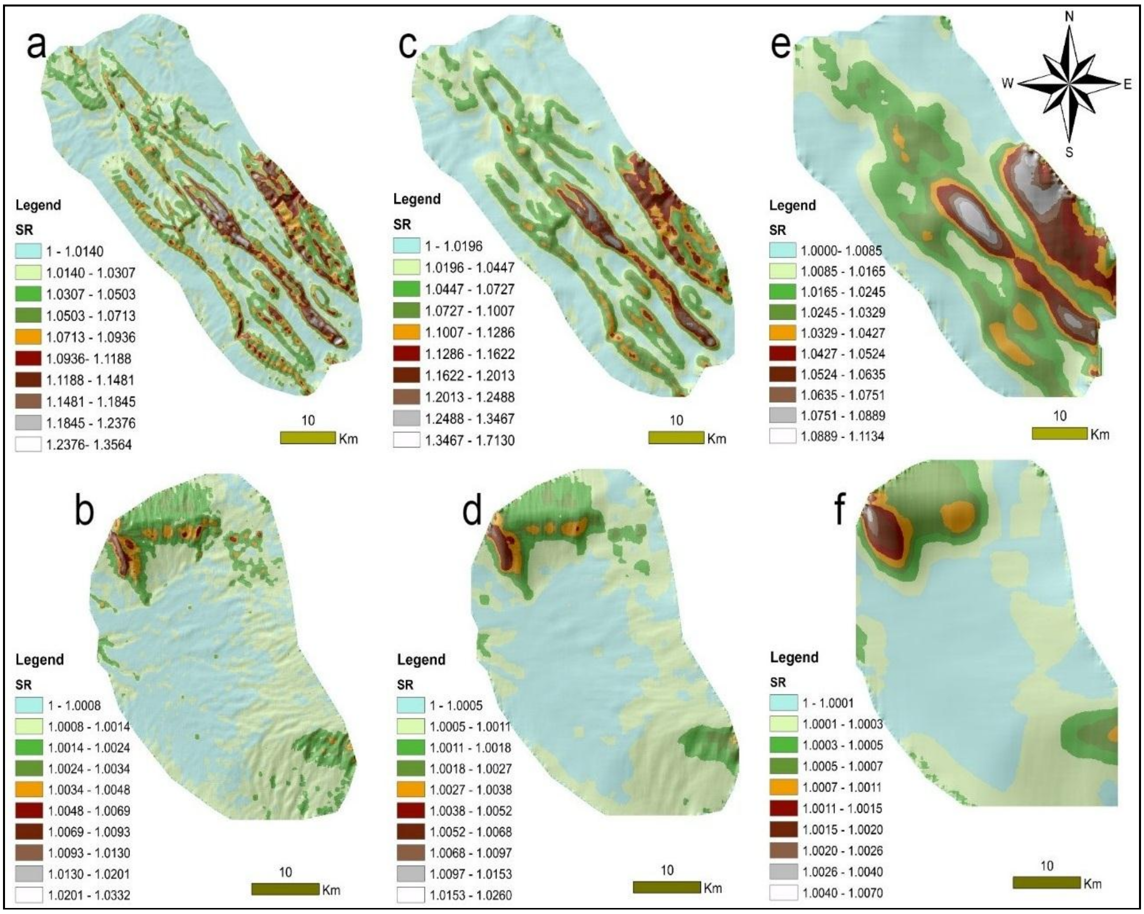

Figure 6: Surface roughness (SR) maps computed from 51 × 51 cells MWZ in the studied areas; **a and b)** ALOS of PALSAR DEM (12.5 m), **c and d)** of SRTMDEM (30 m), and **(e and f)** of SRTM DEM (90 m).

Moreover, the findings of more suitable MWZ (100 × 100 pixels) for analyzing SR for all selected DEMs in this research have been shown in Figure 7. The SR value in area one ranges from 1 to1.2629, 1 to 1.7130, and 1 to 1.1134 for ALOS PALSAR DEM (12.5 m), SRTM DEM (30 m), and SRTM DEM (90 m), respectively (Figures 7a, c and e), although SR values of area two are range between 1 and 1.0333 1 and 1.0256, and 1 and 1.0034 for the same above order of DEMs resolutions, respectively (Figures 7b, d and f). It is generally accepted that plane or flat surfaces are presented by SR values close to 1, whereas higher values of SR indicate rough or irregular surfaces. The broad valleys, plains, in the neighboring synclines, and tips of plunging of anticlines have the lowest in the selected areas, such as Harir plain in the northwestern part of area one and almost parts of area two which are poorly incised landforms (Amine *et al*., 2020).

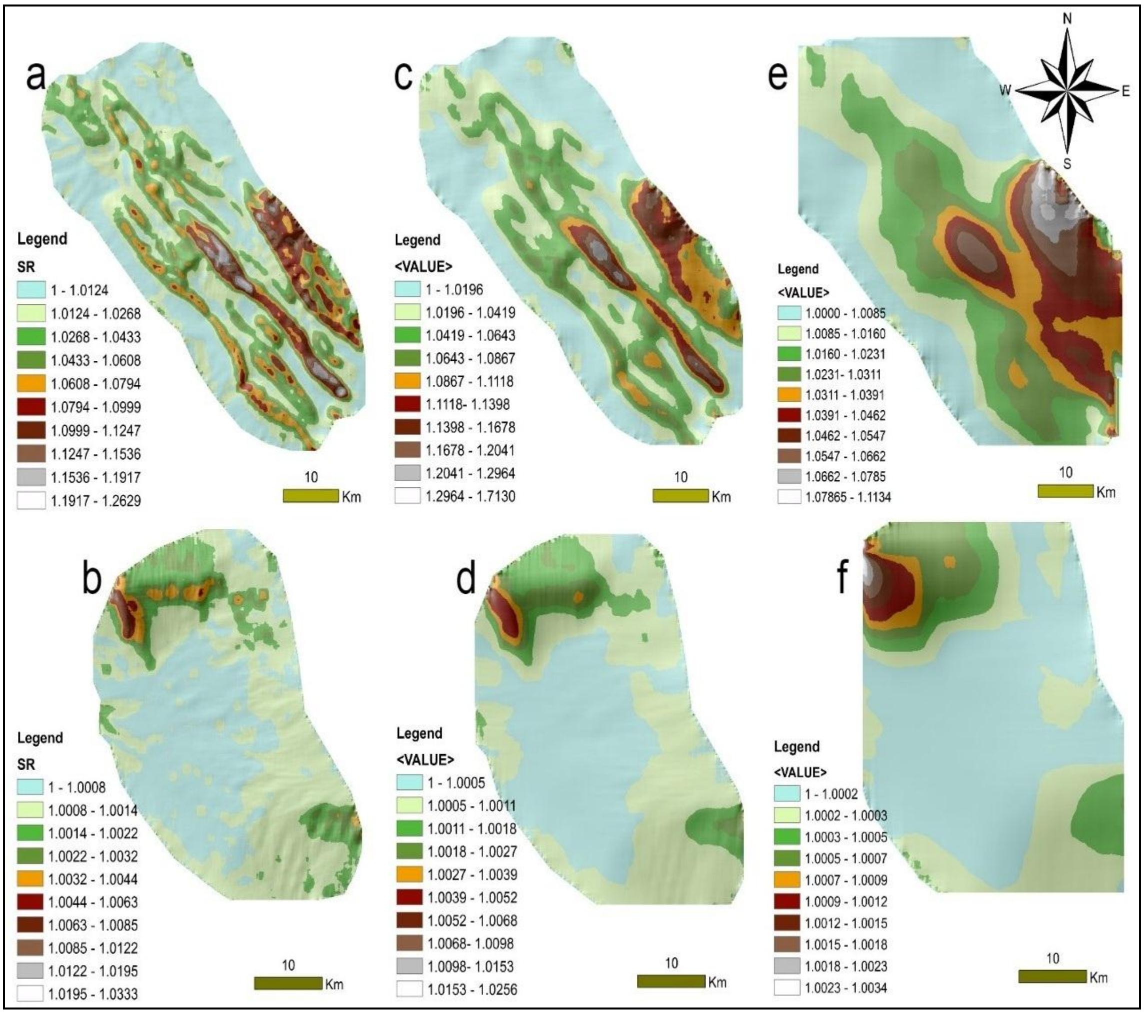

Figure 7: Surface roughness (SR) maps computed from 100 × 100 cells MWZ in the studied areas; **a and b)** of ALOS PALSAR DEM (12.5 m), **c and d)** of SRTMDEM (30 m), and **(e and f)** of SRTM DEM (90 m).

Although, the highest values of SR are related to water gaps' locations, the central and the west segments of the hinge of Safeen and the west segment of Shakrok anticlines, which were strongly incised by wind gaps have the highest values of SR in area one. Also, Bani Bawi, Pirmam, and Khatibian anticlines in area one have low to close moderate values of SR based on DEMs resolutions, where ALOS PALSAR DEM (12.5 m) is considered as input data for most parts of the Safeen anticline, such as east and west segments and a small part of the west of Shakrok anticline have highest SR values which are maturity landforms in the area, other areas have low to moderate values of SR. Moreover, SRTM (30 m) and (90 m) have been considered the same interpretations could be applied to the Bani Bawi, Pirmam, and Khatibian anticlines in addition some parts of Shakrok and Safeen anticlines indicate low SR values, which are poorly engraved landscapes, but the higher values of SR are extended in dissected landforms, such as west segments of Safeen and Shakrok anticlines when SRTM (90 m) considerate where all calculation have done on 51 × 51 cells MWZ. When 100 × 100 pixels MWZ is considered for calculation and determination SR, the results of SR values become smoother in all parts of the study site, particularly in Safeen anticlines it is obviously detected in area one, which is smoother, especially by using SRTM (90M).

On the other hand, it is indicated that general area two has low SR values from all types of DEMs resolutions and MWZ, because it is a plain area the variation of elevation is low, the higher SR values detected in the northwestern part of area two, which considerate to be present of small hills. The small detail could be detected by using high-resolution DEM and smaller window size as can be seen from using ALOS PALSAR DEM (12.5 m) and 51 × 51 window size compares to other types of DEMs and MWZ.

The findings of SR values change with varying the DEMs resolution as input data and changing MWZ (Figures 6 and 7). Similarly, several researchers have detected the same results (Andreani *et al*., 2014; Zebari *et al*., 2019). The smoother calculations and measurements about SR can be obtained from larger moving neighborhood sizes, therefore, 100×100 MWZ has been found a reasonable tool for mountainous areas. Moreover, the high-resolution DEM can be effectively used for detecting detail SR, especially in flat and small areas.

CONCLUSION

Several conceptual frameworks, measurements, and implementation of surface roughness through geosciences and environmental sciences have been reviewed and discussed to outline both the significance of determination surface roughness analysis in each research and emphasized the scope for transplantation of concepts and techniques for various purposes. The SR is a significant parameter for analyzing landscape development and is used for investigating various earth and environmental issues. It was conducted that remotely sensed data with assist of GIS plays an effective role in determining the SR of landforms.

Calculations of this study conducted that high-resolution DEMs would be valuable to provide more detailed and meaningful results about SR concerning small MWZ in investigating small areas while studying large-scale areas (particularly mountainous areas) using moderate to coarse resolution and large MWZ required to obtain consistent and significant results for SR. Therefore, the results indicated that using (100 × 100 cells) MWZ on SRTM DEM (30 m and 90 m) resolutions are more suitable for studying SR of large landscapes (hundreds of meters broad areas). It has shown that the east and west segments of Safeen and almost the west segment of Shakrok anticlines in area one have the highest values of SR due to extremely incised and the presence of wind gaps which indicate advanced stage corrosion and more maturity landforms, while other parts of Shakrok and Safeen anticlines, Bani Bawi, Pirmam, and Khatibian anticlines present low SR values which poorly dissected landscapes which are comparatively smooth surfaces in the area one. Alternatively, in general, area two has low RS values, which have not been or very poorly dissected landforms because it is a flat area and has low incision at elevated.

It is recommended that in producing temporal SR analysis, in order to provide the periodic RS distribution maps, the update DEM is required to be used because the concepts of SR distribution maps might not be reliable for a long time due to the likelihood of changing the land cover/ use and topographic of the area over time. It is also suggested to consider multi-parameters and modified models to analyze the dependable results of SR.

CONFLICT OF INTEREST

On behalf of the authors, the corresponding author states that there is no conflict of interest.

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REFERENCES

Abbas, M.R., Hason, M.M., Ahmad, B.B.and Abbas, T.R.J.a.J.O.G., 2020. Surface roughness distribution map for Iraq using satellite data and GIS techniques. Vol.13, p. 1 – 13.

Al-Attar, Z.T., Othman, A.A., Al-Hakari, S.H.S., Obaid, A.K., Salar, S.G. and Liesenberg, V.J.E.E.S., 2022. A neotectonic statistical assessment through watershed geomorphic analysis: a case study in the Greater Zab River Basin, Turkey – Iraq. Vol.81, p. 1 – 26.

Amine, A., El Ouardi, H., Zebari, M., El Makrini, H., Habibi, M.J.a.C. and Geosciences, 2020. Relative landscape maturity in the South Rifian ridges (NW Morocco): Inferences from DEM-based surface indices analysis. 6, 100027.

Andreani, L. and Gloaguen, R.J.E.S.D., 2016. Geomorphic analysis of transient landscapes in the Sierra Madre de Chiapas and Maya Mountains (northern Central America): implications for the North American–Caribbean–Cocos plate boundary. Vol.4, p. 71 – 102.

Andreani, L., Stanek, K.P., Gloaguen, R., Krentz, O.and Domínguez-González, L.J.R.S., 2014. DEM-based analysis of interactions between tectonics and landscapes in the Ore Mountains and Eger Rift (East Germany and NW Czech Republic). Vol.6, p. 7971 – 8001.

Asal, F.F.J.J.O.G.I.S., 2019. Creation and Analysis of Earth's Surface Roughness Maps from Airborne LiDAR Measurements in Downtown Urban Landscape. Vol.11, 212pp.

Berti, M., Corsini, A. and Daehne, A.J.G., 2013. Comparative analysis of surface roughness algorithms for the identification of active landslides. Vol.182, p. 1 – 18.

Dosky, J.J.M., 2002. Structural study along selected sections across Safin Anticline (Kurdistan–Iraq), University of Salahaddin, Iraq 129pp.

Fatah, K.K., Seeyan, S. and Jirjees, S.J.T.I.G.J., 2020. Morphometric analysis using geo-information techniques for different watersheds in northeastern part of Erbil City, Kurdistan Region, North Iraq. p. 88 – 104.

Frankel, K.L. and Dolan, J.F.J.J.O.G.R.E.S., 2007. Characterizing arid region alluvial fan surface roughness with airborne laser swath mapping digital topographic data. 112pp.

Gharechelou, S., Tateishi, R. and A. Johnson, B.J.R.S., 2018. A Simple Method for the Parameterization of Surface Roughness from Microwave Remote Sensing. Vol.10, 1711pp.

Grohmann, C.H., Smith, M. and Riccomini, C.J.P.O.G., 2009. Surface roughness of topography: A multi-scale analysis of landform elements in Midland Valley, Scotland. Vol.31, p. 140 – 148.

Grohmann, C.H., Smith, M.J., Riccomini, C.J.I.T.O.G. and Sensing, R., 2010. Multiscale analysis of topographic surface roughness in the Midland Valley, Scotland. Vol.49, p. 1200 – 1213.

Grohmann, C.H.J.C. and Geosciences, 2004. Morphometric analysis in geographic information systems: applications of free software GRASS and R. 30, p. 1055 – 1067.

Hani, A.F.M., Sathyamoorthy, D., Asirvadam, V.S.J.C. and Geosciences, 2011. A method for computation of surface roughness of digital elevation model terrains via multiscale analysis. Vol.37, p. 177 – 192.

Hobson, R. 2019. Surface roughness in topography: quantitative approach. Spatial analysis in geomorphology. Routledge.

Hu, L., He, Z., Liu, J. and Zheng, C.J.E., 2015. Method for measuring the information content of terrain from digital elevation models. Vol.17, 7021 – 7051.

Jassim, S.and Goff, J. 2006. Geology of Iraq: DOLIN, sro, distributed by Geological Society of London.

Jhaldiyal, A., Gupta, K., Gupta, P., Reddy, S. and Kumar, P.J.V.M., 2016. Review of Methods for Estimating Urban Surface Roughness. 42pp.

Korzeniowska, K. and Korup, O., 2016. Mapping gullies using terrain surface roughness. Proceedings of the 19th AGILE International Conference on Geographic Information Science (AGILE 2016), Helsinki, Finland, 2016. p. 14 – 17.

Luo, W., Arvidson, R.E., Sultan, M., Becker, R., Katherine Crombie, M., Sturchio, N. and El Alfy, Z.J.G.S.O.a.B., 1997. Ground-water sapping processes, western desert, Egypt. Vol.109, p. 43 – 62.

Minár, J. and Evans, I.S.J.G., 2008. Elementary forms for land surface segmentation: The theoretical basis of terrain analysis and geomorphological mapping. Vol.95, p. 236 – 259.

Omar, A.A., 2011. Abnormal deflection in the some folded axes within Zagros fold and Thrust Belt, Northern Iraq, Mirawa-Mawaran synclinal axis as a case Study. Proceedings of the 4th WSEAS international conference on Energy and development-environment-biomedicine, 2011. p. 17 – 30.

Riley, S.J., Degloria, S.D. and Elliot, R.J.I.J.O.S., 1999. Index that quantifies topographic heterogeneity. Vol.5, p. 23 – 27.

Sajadi, P., Singh, A., Mukherjee, S., Luo, P., Chapi, K. and Salari, M.J.G.I., 2021. Multivariate statistical analysis of relationship between tectonic activity and drainage behavior in Qorveh-Dehgolan basin Kurdistan, Iran. Vol.36, p. 540 – 562.

Shepard, M.K., Campbell, B.A., Bulmer, M.H., Farr, T.G., Gaddis, L.R. and Plaut, J.J.J.J.O.G.R.P., 2001. The roughness of natural terrain: A planetary and remote sensing perspective. Vol.106, 32777 – 32795.

Sissakian, V.K. and Fouad, S.F.J.I.G.S.P., 2014. Baghdad, Iraq 2014. Geological Map of Sulaimaniyah Quadrangle, scale 1: 250 000.

Smith, M.W.J.E.-S.R., 2014. Roughness in the earth sciences. Vol.136, p. 202 – 225.

Tay, L. and Teng, H.J.a.J.O.G., 2008. Roughness index and fractal dimension for surface information extraction. Vol.8, p. 21 – 24.

Tonietto, L., Gonzaga, L., Veronez, M.R., Kazmierczak, C.D.S., Arnold, D.C.M. and Costa, C.a.D.J.S.R., 2019. New method for evaluating surface roughness parameters acquired by laser scanning. Vol.9, p. 1 – 16.

Yuan, C., Ren, C. and Ng, E.J.U.C., 2014. GIS-based surface roughness evaluation in the urban planning system to improve the wind environment–A study in Wuhan, China. Vol.10, p. 585 – 593.

Zebari, M., Grützner, C., Navabpour, P. and Ustaszewski, K.J.S.E., 2019. Relative timing of uplift along the Zagros Mountain Front Flexure (Kurdistan Region of Iraq): Constrained by geomorphic indices and landscape evolution modeling. Vol.10, p. 663 – 682.

Zebari, M., Navabpour, P., Grützner, C. and Ustaszewski, K., 2018. Assessing Relative Landscape Maturity of Anticlines along the NW Segment of the Zagros Mountain Front Flexure, Kurdistan Region of Iraq. EGU General Assembly Conference Abstracts, 2018. 17446pp.

Zebari, M.M. and Burberry, C.M.J.G., 2015. 4-D evolution of anticlines and implications for hydrocarbon exploration within the Zagros Fold-Thrust Belt, Kurdistan Region, Iraq. Vol.20, p. 161 – 188.

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